ITEA Journal 2008; 29: 267–274

Improving Program Success by Applying Systems Engineering and Reliability Growth Analysis

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The Stryker Mobile Gun System (MGS) is a major, complex weapon system that presented a challenge in meeting its reliability requirement due to new technology revolving around the system's automatic ammunition handling system (AHS). However, as a result of a successful reliability growth management program, the Stryker MGS program experienced an unprecedented growth rate during developmental testing that led the program to meet its requirement. The program employed an effective systems engineering process to identify and implement effective corrective actions and adopted the Reliability Growth Analysis methodology to accurately track the resulting reliability growth. These tools provided the product manager with the information necessary to allocate resources and maintain support for the program throughout its development. Other similar complex systems may benefit by applying these processes and tools.

Key words: Reliability; Reliability Growth Analysis; reliability growth test; systems engineering.

MIL-HDBK-189 states that *"the Government's materiel acquisition process for new military systems requiring development is invariably complex and difficult for many reasons. Generally, these systems require new technologies and represent a challenge to the state of the art. Moreover, the requirements for reliability, maintainability and other performance parameters are usually highly demanding. Reliability growth management procedures have been developed for addressing the above problem."*

Stryker Mobile Gun System (MGS) was one of those complex and difficult development systems that presented a challenge in meeting the reliability requirement due to the new technology revolving around the system's automatic ammunition handling system (AHS). The AHS represents a significant portion of the vehicle's unique mission equipment package. Although reliability improvements were made to other subsystems, the AHS redesign contributed the most to the system's reliability growth. As a result of a successful reliability growth management program, the Stryker MGS program experienced successful reliability growth with an unprecedented growth rate during test.

This article reports on lessons learned from initiating a successful reliability growth management program that was based upon an effective systems engineering process to identify and implement effective corrective actions. It discusses the adoption of the Reliability Growth Analysis (RGA) methodology on the MGS development that provided the program management office with a tool to track the reliability growth accurately, which led to a successful reliability growth test. Additionally, the development of an idealized reliability growth curve provided astandard to measure progress. Finally, the tests were conducted

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Improving Program Success by Applying Systems Engineering and Reliability Growth Analysis**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Tank Automotive-Armament Command,Tank Automitive Research & Development Center,Warren,Mi,48397-5000**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

in accordance with the system's operational profile and the assessment of data groups, based upon a balanced ratio of operational parameters provided, helped ensure the conclusions were relevant to intended operational use. Early and accurate assessment of the system's reliability was essential to maintain support for the program as it progressed through development, production, and fielding to soldiers.

RGA versus engineering analysis

Based on the MIL-HDBK-189, Reliability growth is the improvement in a reliability parameter over a period of time due to changes in product design or the manufacturing process. It occurs by surfacing failure modes and implementing effective corrective actions. In reliability growth management procedures, MIL-HDBK-189 introduces two methodologies, RGA and engineering analysis, which can be used to estimate the demonstrated reliability of the system if the configuration of the system is changing as a result of corrective actions to problem failure modes during testing. It also states that RGA is a preferred method since it provides an objective mathematical assessment of the reliability of the system being tested, that is, unless the RGA procedures cannot be applied to the test data because of data anomalies. It should be noted that if there is no change of configuration of the system during testing, then reliability growth procedures would not be necessary and the demonstrated reliability value would be cumulative reliability which is determined simply by dividing the total test time/miles/rounds, etc., by the number of charged failures.

The conventional way of assessing a demonstrated reliability using engineering analysis through an assessment conference has been used throughout combat vehicle history. For combat systems at Tank Automotive-armament Command (TACOM) and Program Executive Office Ground Combat Systems (PEO GCS), the engineering analysis technique has been the standard approach for estimating demonstrated reliability. However, the engineering analysis has several weaknesses. It is subjective and will therefore tend to be less definitive than data analysis based on reliability growth procedures. Engineering analysis involves using engineering judgment to assess the effectiveness of fixes that have been incorporated during the test program to determine the demonstrated reliability value. This technique uses the cumulative reliability adjusted based on a Fix Effectiveness Factor (FEF) applied for all fixes implemented. The FEF essentially provides the system "credit" for fixes applied and ranges from 0.0 (not effective) to 1.0 (failure mode eliminated).

To assess the demonstrated reliability using this conventional methodology, one typically waits until the test is completed to gain enough validated mileage after the fixes. The estimation of FEF is usually based solely on the concrete evidence from test data that the failure rate has been reduced in the operational environment and that it does not create any new failure modes. This methodology was not suitable for the Stryker MGS Production Verification Test (PVT), which lasted almost two years as the system went through many configuration changes due to corrective actions being implemented throughout the test period. Using this approach, the effectiveness of the fixes could not be tracked during the test and therefore the reliability growth could not be reported to the stakeholders.

On the other hand, the RGA technique lets the data speak for itself. In the presence of reliability growth, the data from earlier configurations may not be representative of the current configuration of the system. On the other hand, the most recent test data, which would best represent the current system configuration, may be limited so that an estimate based upon the recent data would not, by itself, be sufficient for a valid determination of reliability. Because of this situation, RGA offers a viable method for combining test data from several configurations to obtain a demonstrated reliability estimate for the current system configuration. Therefore, RGA allows for the effects of even recently introduced fixes into the system as its calculation incorporates the trend of growth established over the history, to date, of the development program.

Stryker Mobile Gun System is one of the programs that used RGA technique effectively to assess a demonstrated reliability during the system reliability availability and maintainability (RAM) testing during 2006–2008. The adoption of both the RGA technique along with an effective system engineering process led the MGS program through a very successful reliability growth test. This was accomplished after low reliability was demonstrated during its Production Qualification Test (PQT). Adopting the RGA methodology did require acceptance from the evaluation and user stakeholders.

What is the Stryker Mobile Gun System (MGS)?

MGS *(Figure 1)* is one of 10 variants of the Stryker Family of Vehicles (FOV). MGS was one of the two developmental variants while the other eight variants were ready for production based on technology readiness, integration readiness, and manufacturing readiness. The Stryker FOV shares a common chassis

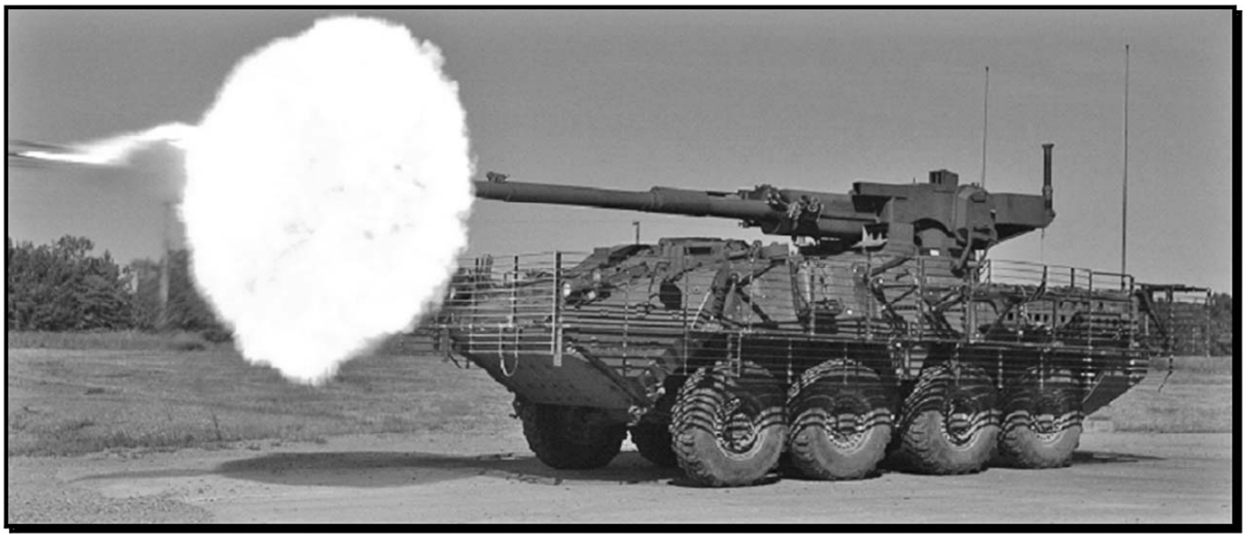

Figure 1. Stryker Mobile Gun System (MGS)—bunker buster

and many common components from the base vehicle—the Infantry Carrier Vehicle. Each variant is equipped with its unique mission equipment package. The MGS is equipped with a turreted, fully stabilized 105-mm main gun; a 7.62-mm coaxial mounted machinegun; a .50 caliber machinegun; and day and night optics. The 105-mm main gun ammunition is moved around the system and loaded in the breech by an automatic AHS. The AHS replaces some of the functions normally conducted by a loader in other weapon systems, e.g., Abrams Main Battle Tank.

The MGS went into PQT where the system demonstrated a small fraction of its system reliability requirement. The demonstrated reliability was too low and it was concluded that the MGS would require a redesign effort. The PQT was terminated about two thirds of the way through test. After reviewing and studying all the failure modes identified during PQT, it was concluded that the weakest link was the AHS replenisher. A redesign effort was launched for this and other AHS issues. Also, additional RAM test was conducted to prove the fixes that came in late in PQT, and the RAM community used the data from PQT and additional RAM testing to estimate where the reliability of the MGS would be at the start of the next test phase—PVT.

An accelerated reliability growth test was conducted upon the completion of the redesign of the replenisher and other AHS items. The test verified that the redesigned replenisher was robust. Before PVT was initiated, a short contractor's shake down test was conducted on all the redesigned AHS components including the AHS replenisher. The results of the test indicated that the system still had a challenge to meet the established reliability requirement of the mission equipment package. The Army community accepted the MGS PVT as a reliability growth test in place of a traditional verification test.

Reliability growth test

Ideally, the pure design process would be perfect with no testing required to improve reliability to meet the requirement. However, analytical tools, models, and engineering judgment are not perfect, so testing is always needed to fill in the gaps in knowledge and understanding. These tests have been specifically planned to stress the system components to predetermined realistic levels at which inadequate design features will surface as system failures. These failures are analyzed, design modifications incorporated, and then the modified system is tested to verify the validity of the design changes.

Most systems in the Army still rely heavily on the test-in rather than the design-in approach for reliability growth although a design-in approach is far more cost effective. This is due to ineffective design-in reliability practices. Making design-in reliability tools more effective will remain a challenge in the reliability domain. As a result of an ineffective design-in reliability practice, most systems have the initial reliability at the beginning of development test too low which leads to a lengthy test and often failure to meet the requirement at the end of test. The MGS contractor's brief shake down test after the redesign also showed the reliability growth of the MGS mission equipment package would have to rely heavily on the test-in approach during Government PVT.

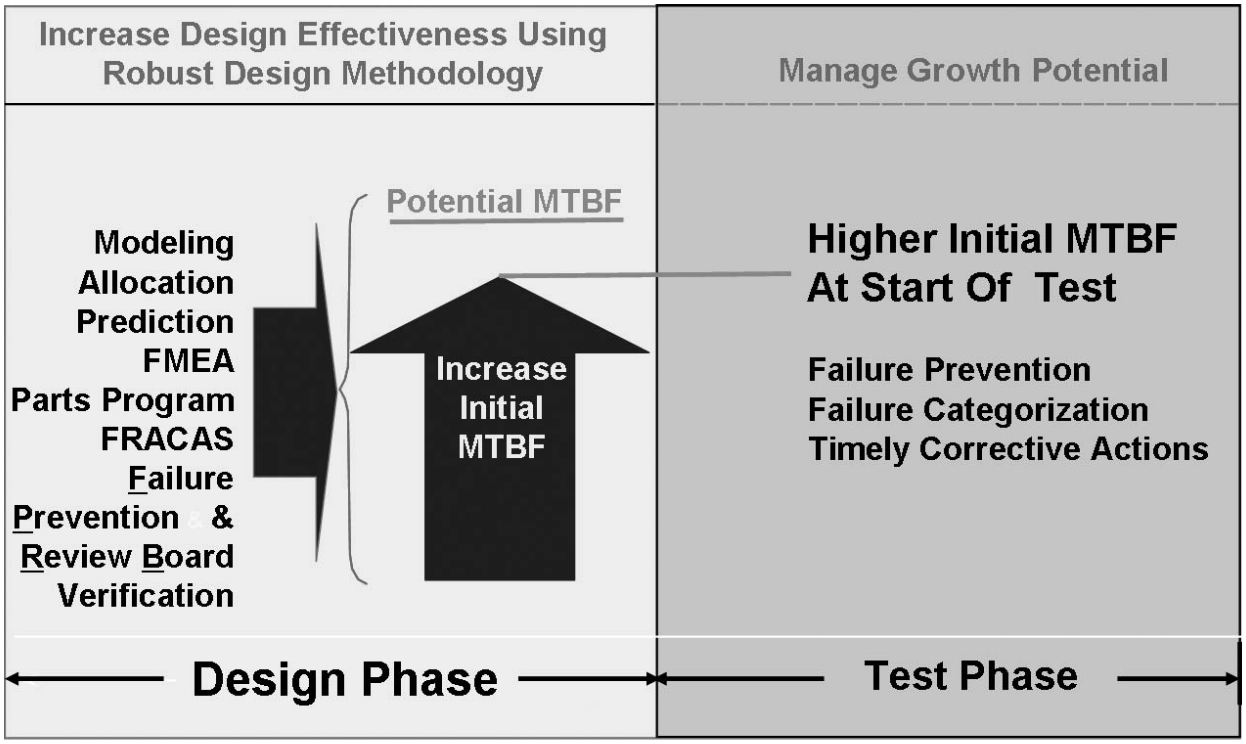

Figure 2. System engineering approach to reliability

This testing philosophy utilizes the Test-Analyze-Fix-Test (TAFT) procedure as the basic catalyst in achieving system reliability growth. The ultimate goal of a reliability growth program is to increase system reliability to the stated requirement levels by eliminating a sufficient number of inherent system failure modes.

Systems engineering

The growth rate experienced is a function of the design team's ability to identify and implement effective corrective actions and how quickly they are implemented. To achieve sufficient growth rate, a sufficient number of inherent system failure modes have to be eliminated. The U.S. Army Materiel Systems Analysis Activity (AMSAA) reports, on average, design changes are 70 percent effective in correcting a problem. The focus of MGS reliability growth management was to identify and close out failure modes from failure mode effects analysis and tests. The materiel developer's system engineering approach used during design phase and test phase for MGS reliability growth is depicted in *Figure 2*.

During the redesign phase after PQT, the system engineering process included performing Failure Mode Effects Analysis to identify, correct and close out issues found during design reviews and analyses as a preemptive action to potentially eliminate or greatly reduce the existing failure rate. This engineering process influenced the design to consider reliability so that the initial reliability of the system is high. However, initial prototype models of complex weapon systems will invariably have inherent reliability and performance deficiencies that generally could not have been foreseen and eliminated in early design states.

During the test phase, as performance deficiencies are observed and failures are uncovered, design engineers should properly analyze failures. Timely implementation of the corrective actions that can be taken to prevent recurrence or minimize the effects of failure are critical to any reliability growth program. The materiel developer implemented a very robust system engineering approach through a very effective and aggressive failure analysis and corrective action system with daily oversight activities by a Failure Prevention Review Board. The process included a closed-loop reporting system ensuring all test incidents were addressed. This systems engineering process during test phase was proven to be very effective with significant MGS mission equipment package reliability growth during PVT.

Constructing idealized growth for MGS mission equipment package

For a system under development, reliability generally increases rapidly early on and then at a much slower rate towards the end of development. It is useful at the

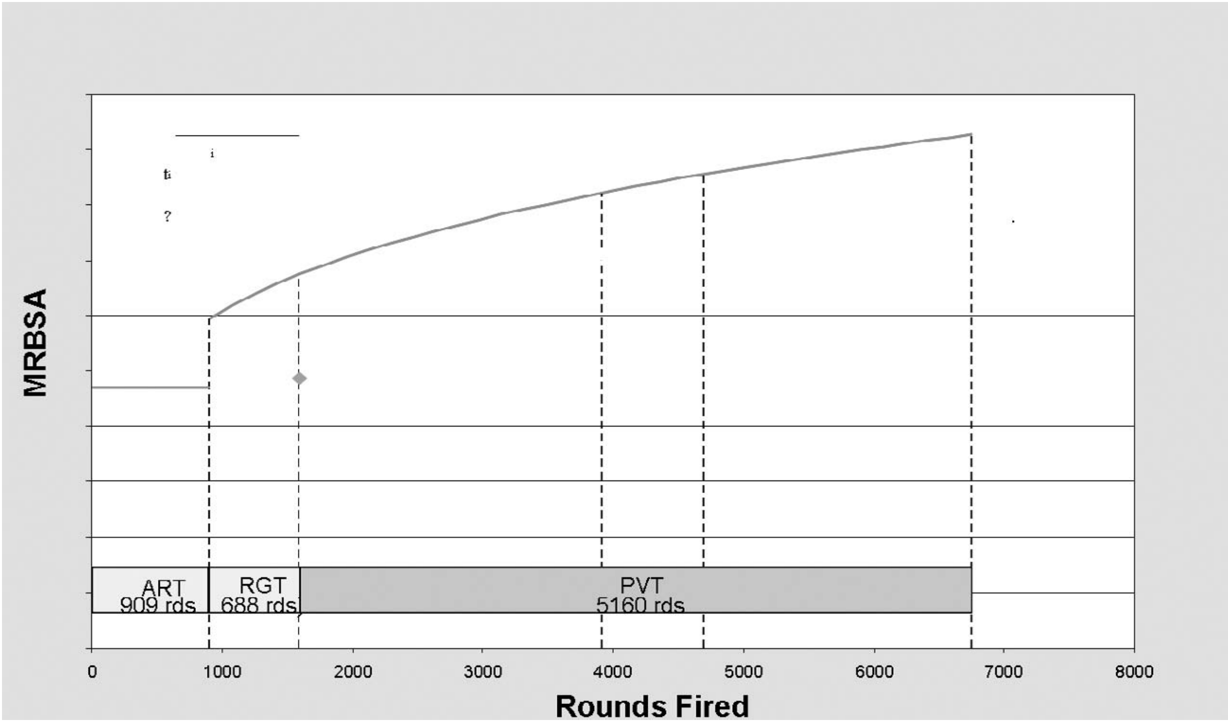

Figure 3. Idealized growth curve for Stryker Mobile Gun System (MGS) mission equipment package

beginning of a development program to depict the growth in reliability as a smooth curve which rises at slower and slower rates as time progresses. This curve does not necessarily convey precisely how the reliability will actually grow during development. Its purpose is to present a preliminary view as to how a program should be progressing in order for the final reliability requirements to be realized.

The RAM Integrated Production Team (IPT) led by the Army Evaluation Center (AEC) developed an idealized growth curve for the MGS mission equipment package using the previous test results as the initial reliability and the user's requirement as the target at the end of PVT. A conservative growth rate of 0.22 was used for planning purpose. The growth rate assumption was based on the historical combat system experiences. The idealized curve also showed that the system could reasonably be expected to meet its requirement. The idealized reliability growth curve developed for the MGS mission equipment package is depicted in *Figure 3*.

Growth tracking during MGS PVT

Reliability growth tracking is a process that allows management personnel the opportunity to gauge the progress of the reliability effort for a system by obtaining a demonstrated numerical measure of the system's reliability during a development program based on test data. Objectives for the reliability tracking include determining if system reliability is increasing with time and to what degree, and estimating the demonstrated reliability—an estimate based on test data for the system configuration under test at the end of each test phase.

The Stryker MGS PVT was conducted in cycles of 1,000 miles and 86 main gun rounds fired, approximating the operational mode summary/mission profile (OMS/MP). During PVT, three MGS vehicles were subject to run 20,000 miles and fired 1,720 main gun rounds each, for a total 60,000 miles and 5,160 rounds over the two-year period.

Test Incident Reports were prepared by the test centers (Aberdeen Proving Ground, MD and Yuma Proving Ground, AZ) and scored by the RAM scoring members (consisting of the evaluator, materiel developer and user representative) establishing the official Army database for estimating reliability. The data is further subdivided into chassis and mission equipment package failures. Since the chassis reliability was already proven as a common Stryker FOV subsystem, only the MGS mission equipment package reliability was tracked for growth. At the end of test, the MGS chassis reliability did prove to be reliable—just like the other variants in the Stryker FOV.

To track the reliability growth during PVT, the RAM IPT led by AEC developed a data grouping methodology. Since PVT was Test-Analyze-Fix-Test and the fixes were being implemented as they were

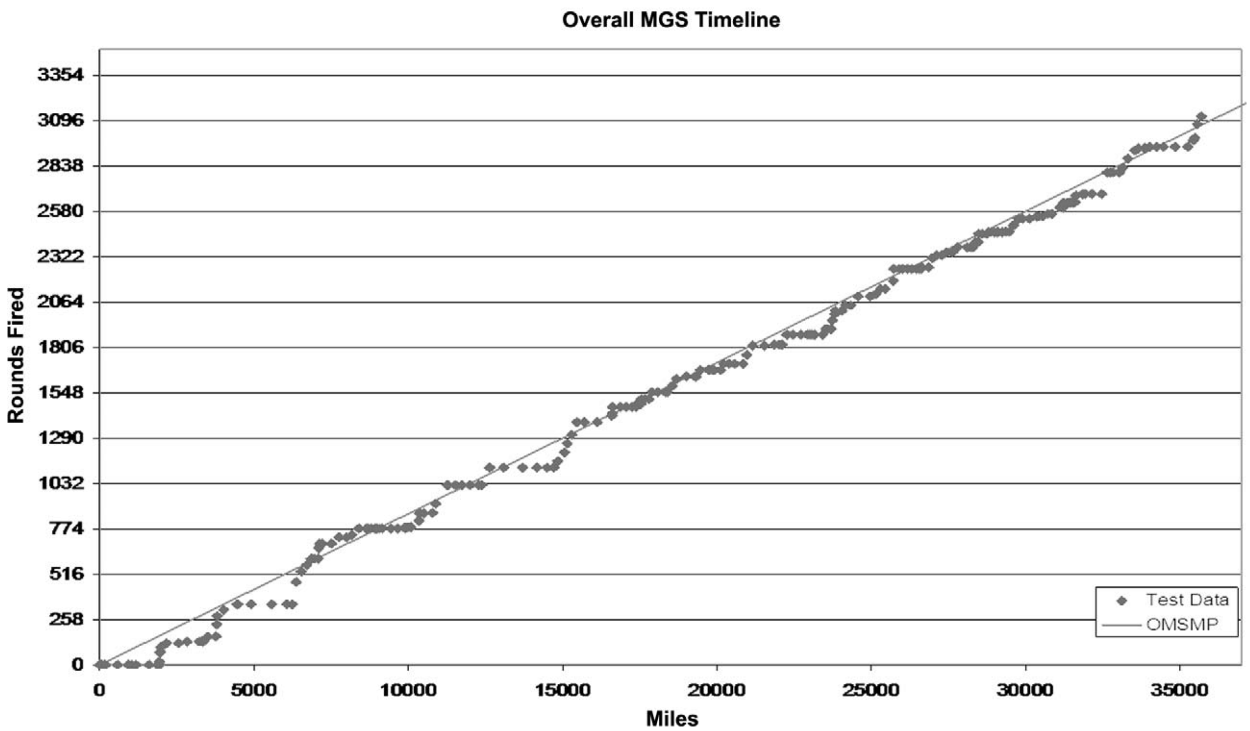

Figure 4. Cumulative rounds versus cumulative miles for all three vehicles in testing

available (in a rather random fashion) the RAM community had to establish a method to divide the PVT into distinct phases to track the growth of reliability. The approach for grouping the data first established a single timeline of events. This was done using daily updates from the test centers that documented the mileage accumulation and rounds fired for each of the test vehicles. The cumulative mileage and rounds fired were then summarized by date. The reliability failures Test Incident Reports were then aligned by date with these values to establish the timeline. *Figure 4* shows an example of the single timeline for the cumulative vehicle data as a function of the OMS/MP.

In order to plot the estimated expected mean time between failure (MTBF) versus the observed average MTBF, the Army Materiel System Analysis Activity (AMSAA) Reliability Growth Tracking Model for Continuous data (RGTM-C), which was selected to be used for MGS PVT, requires that each group contain at least one failure. Therefore, group selection was adjusted to accommodate this requirement. It became apparent as the MGS RAM test progressed that selection of the groups was becoming very subjective. Additionally, vehicle modifications, corrective actions, downtime for vehicle maintenance, and test conduct were impacting the analysis. The test firings were not evenly distributed across a test cycle but were conducted in groups when time permitted. Other contributing factors were firing range availability and weather conditions (e.g., main gun rounds could not be fired on test ranges when winds were high).

An alternative method was sought for establishing the groups used in the analysis. The approach for selecting the groups used three criteria:

- Have a ratio of rounds-to-miles closely approximating the OMS/MP (86:1,000) (minimize the delta between the number of rounds fired versus the expected value from the OMS/MP),
- For the vehicles within the groups, maximize the number of individual vehicles that are close to a multiple of 86 rounds,
- All test vehicles are represented in the group, i.e., at least one failure.

This method of grouping the data works for finding a mean mission equipment package reliability estimate given the large difference in mission equipment reliability of the individual vehicles. By requiring each vehicle to be represented in the group, impacts from extended downtime, configuration differences, and main gun firing were mitigated to the maximum extent possible. While this method is still subjective, the technique minimizes the variance in model output based on group selection.

Once the data was grouped, AMSAA RTGM-C was run. The chi-square goodness-of-fit statistic must be equal to or less than the critical value at the chosen

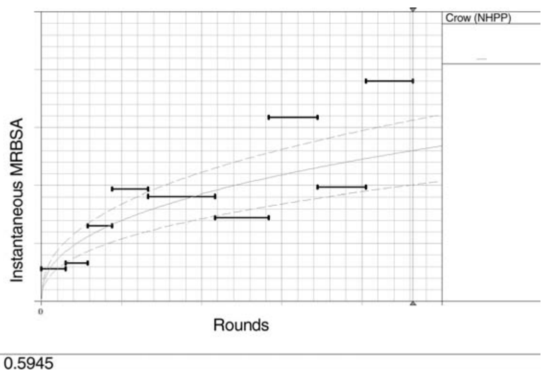

Figure 5. Estimated expected mean time between failure (MTBF) versus observed average MTBF

0.10 level of significance to accept the model. If this condition is met, then the model output is considered a viable estimate of the reliability of the MGS mission equipment package. The model provides estimates of the growth parameter β, the growth rate α (1-β), the scale parameter λ, and the MTBF of the last group. *Figure 5* shows a plot of the estimated expected MTBF versus the observed average MTBF.

Figure 6 shows a plot of the estimated expected and observed average MTBF superimposed on the idealized growth curve. The superimposed plot shows that with approximately two thirds of the PVT completed, the observed average MTBF was close to 0.4 growth rate and was exceeding the idealized growth curve. It also shows that initial reliability at the beginning of the test was much lower than expected which forced the growth rate to be much higher than planned to achieve the target at the end of the test.

The MGS mission equipment package system experienced a significant growth rate, 0.4 during PVT, with the system demonstrating above the target reliability at the end of the test. AMSAA reports the historical growth parameter to be in the range of 0.23–0.53 for time/mileage (continuous) systems. Typically for complex combat systems such as the Abrams Tank and Bradley Fighting Vehicle the growth rates were assessed to be approximately in the range of 0.2–0.25.

Conclusion

Understanding the status of a program at any given point is one of the challenges facing program

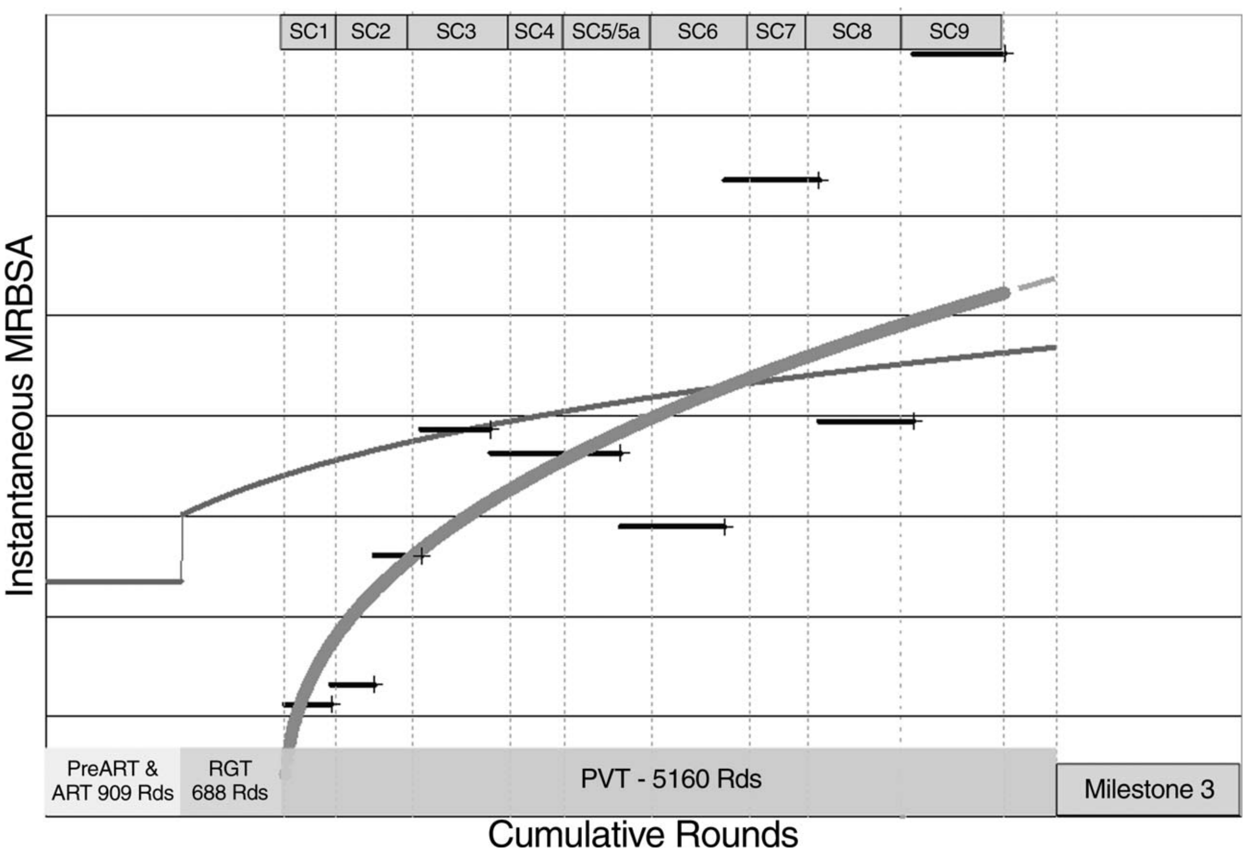

Figure 6. Mobile Gun System (MGS) mission equipment package observed average mean time between failure (MTBF) superimposed on the idealized growth curve

managers. Increasing system complexity coupled with increasing demand for more reliable systems causes members of the development team to rely on efficient and effective tools to report program health. RGA provides one such tool to understand reliability growth throughout the development without having to wait until the conclusion of development. When program management recognized the challenge lying with the reliability of the MGS mission equipment package after PQT, the Stryker Reliability Integrated Product Team was challenged to develop an effective reliability growth management program to meet the requirement. The Systems Engineering Team assembled reliability tools into disciplined processes and working organizations. When reliability assessment was reached through in-depth analysis coupled with a best fitting methodology, the result was the MGS mission equipment package experienced an unprecedented growth rate during PVT.

The successful mission equipment package system reliability growth program of MGS PVT can be attributed to the following factors:

1. The test program was planned to expose the system to test and stress levels adequate to uncover inherent failure modes.

2. The program office took into consideration the requirements of the test schedule and resources required to support the Test-Analyze-Fix-Test procedure.

3. The materiel developer conducted an effective system engineering process to identify and implement effective corrective actions.

4. The Stryker Reliability Integrated Product Team applied reliability growth analysis techniques and developed a methodology to track and assess the reliability growth at every test phase.

There is no simple way to ensure program success. However, program managers that encourage and demand a disciplined systems engineering process, enabled by fact-based recommendations, and implement tools to assess how the system reacts to changes will certainly increase the development success rates of challenging, complex systems. ❑

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